



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:  
**02.10.1996 Bulletin 1996/40**

(51) Int. Cl.<sup>6</sup>: **H01L 31/068, H01L 31/0288**

(21) Application number: **96105098.6**

(22) Date of filing: **29.03.1996**

(84) Designated Contracting States:  
**CH DE FR GB LI**

(72) Inventor: **Hisamatsu, Tadashi**  
**Tsukuba-shi, Ibaraki (JP)**

(30) Priority: **30.03.1995 JP 72880/95**  
**30.01.1996 JP 13891/96**

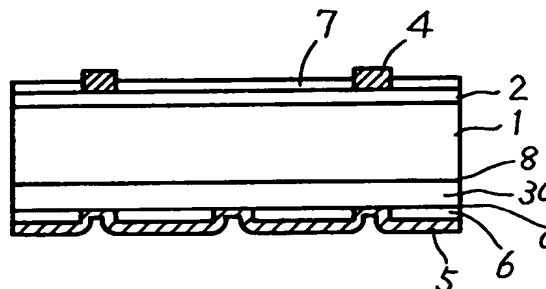
(74) Representative: **TER MEER - MÜLLER -**  
**STEINMEISTER & PARTNER**  
**Mauerkircherstrasse 45**  
**81679 München (DE)**

(71) Applicant: **SHARP KABUSHIKI KAISHA**  
**Osaka-shi Osaka 545 (JP)**

(54) **Silicon solar cell and fabrication method thereof**

(57) A silicon solar cell includes a p type silicon substrate (1), an n type diffusion layer (2) formed at a first main surface side of the substrate, and a p<sup>+</sup> layer (3a) of high doping concentration formed at a second main surface side of the substrate (1) by ion-implantation of group III element having an atomic radius greater than that of a Si atom. Al is preferably used as the group III element.

**FIG. 1**



## D scription

### BACKGROUND OF THE INVENTION

#### Field of the Invention

The present invention relates to solar cells, and more particularly to a silicon space solar cell preferably used as a power source of a satellite used in outer space where the irradiation intensity of radioactive rays and ultraviolet rays is great.

#### Description of the Background Art

One of the most general space solar cells currently used as the power source of a satellite is a Si solar cell with single crystal (Si) as the base material. In accordance with the greater size, multifunction, and long life time of satellites, the need of high output and improvement in the radiation resistance of a Si space solar cell is increasing. Means for high output and improvement in radiation resistance in Si space solar cells will be described hereinafter.

Fig. 8 is a sectional view schematically showing a basic structure of a BSFR (Back Surface Field and Reflector) type solar cell for practical usage. In the solar cell of Fig. 8, an n type diffusion layer 2 is formed by thermal diffusion at a front light receiving surface of a p type Si substrate 1. A p<sup>+</sup> type layer (BSF layer) 3 is formed similarly by thermal diffusion on the back surface of substrate 1. A front electrode 4 is formed on n type diffusion layer 2, and a back electrode 5 is formed on p<sup>+</sup> type layer 3. P<sup>+</sup> type layer 3 in Fig. 8 serves to improve the collection efficiency of carriers to increase the output of the solar cell. Although not shown in Fig. 8, a back surface reflective layer between p<sup>+</sup> type layer 3 and back electrode 5 for reflecting infrared light, and an anti-reflection coating on the front surface for receiving incident light efficiently are provided. Furthermore, cover glass is adhered in practical usage.

Fig. 9 shows a solar cell developed to further improve the output of the solar cell of Fig. 8. The components of the solar cell of Fig. 9 corresponding to those of the solar cell of Fig. 8 have the same reference characters allotted. More specifically, the basic structure of the solar cell of Fig. 9 is similar to that of Fig. 8 except for the provision of a back surface oxide film 6 and a front surface oxide film 7 at the back surface side and the front surface side, respectively, of substrate 1. Back surface oxide film 6 functions as a passivation film to prevent minority carriers (electrons) generated within p type substrate 1 by light absorption from being recombined with the majority carriers (hole) at the back surface of the cell. Similarly, front surface oxide film 7 functions as a passivation film at the front surface of substrate 1 to prevent minority carriers (hole) generated in n type diffusion layer 2 by light absorption from being recombined with majority carriers (electron) at the front surface of the cell. The solar cell of Fig. 9 allows an out-

put higher than that of the cell of Fig. 8 by preventing recombination of carriers generated by light absorption.

Fig. 10 shows the structure of another solar cell developed to improve the efficiency. The solar cell of Fig. 10 is similar to the solar cell of Fig. 9 provided that p<sup>+</sup> layer 3 is formed only at the proximity of the region where substrate 1 is brought into contact with back electrode 5 via an opening in back surface oxide film 6.

Table 1

Cell	Initial Output Characteristics					Output Characteristics After Electron Irradiation					$\alpha_s$
	Voc(mV)	Isc(mA)	F.F.	Pmax(mW)	Pmax/Top	Voc(mV)	Isc(mA)	F.F.	Pmax(mW)	Pmax/Top	
(a)	605.0	166.0	0.792	79.5	76.6	507.0 (83.8%)	139.8 (84.2%)	0.780 (98.5%)	55.3 (69.5%)	52.4	0.76
(b)	661.0	176.5	0.751	87.7	86.7	516.4 (78.0%)	152.4 (86.1%)	0.756 (99.7%)	59.5 (67.0%)	57.6	0.72
(c)	621.7	173.7	0.763	82.4	75.1	514.5 (82.4%)	152.5 (88.2%)	0.772 (100%)	60.6 (73.3%)	54.6	0.87
(d)	645.4	176.2	0.770	87.6	86.1	544.1 (84.3%)	157.5 (89.4%)	0.770 (100%)	66.0 (75.3%)	63.1	0.74

In Table 1, solar cells (a) and (b) exhibit the initial output characteristic and the output characteristics after being subjected to electron irradiation of energy 1 MeV at  $1 \times 10^{15} \text{e/cm}^2$  corresponding to the solar cells of

Figs. 8 and 10, respectively. In contrast to solar cell (a) of Fig. 8, solar cell (b) of Fig. 10 has the maximum power  $P_{\text{max}}$  improved by approximately 10 % although open circuit voltage  $V_{\text{OC}}$  and short-circuit current  $I_{\text{SC}}$  before and after electron irradiation are high and fill factor FF is slightly low.

The values of the output characteristics of Table 1 are measured using light corresponding to AM0 (solar light of exoatmosphere), and under the temperature of  $28^\circ\text{C}$  except for  $P_{\text{max}} \cdot T_{\text{OP}}$  (mW) representing the maximum power at an operating temperature  $T_{\text{OP}}$ . The value in % in the parenthesis of the output characteristics after electron irradiation indicates the remaining factor with respect to the output characteristic before electron irradiation.  $\alpha_s$  indicates the solar absorptance.

The radiation resistance of a Si space solar cell will be described hereinafter. In general, a space solar cell is subjected to radiation of electrons, protons, neutrons,  $\alpha$ -particles, X-rays, ultraviolet rays, etc. of high energy and high density in the outer space environment, whereby a vacancy in the crystal of the semiconductor substrate of the solar cell, a complex center where a vacancy and an interstitial impurity atom are combined, and a cluster of these defects are formed. These radiation defects electrically act as the recombination center of carriers to reduce the life time and diffusion distance of the minority carriers, whereby the performance of the solar cell is degraded. A Si solar cell for space use is conventionally provided with the following measures (A1) - (A3) to suppress such effects by radiation defect.

(A1) An n-on-p type is selected for the solar cell. Since electrons have a longer life time and diffusion distance than holes, the effect by radiation defect can be relatively reduced by a solar cell of, not the p-on-n type, but of the n-on-p type.

(A2) The thickness of the semiconductor substrate of the solar cell is reduced. A thinner semiconductor substrate results in a fewer absolute number of radiation-induced defects included therein to allow the number of minority carriers captured by these defects reduced.

(A3) The pn junction in the solar cell is provided at a shallow region from the front surface of the semiconductor substrate. In other words, the collection efficiency of the minority carriers generated within the thinned diffusion layer is improved.

However, sufficient radiation resistance cannot be obtained by the solar cells of high output shown in Figs. 9 or 10 even when the above measures of (A1) - (A3) to improve radiation resistance are applied. For example, in Table 1, the output characteristics of a solar cell subjected to electron irradiation of 1 MeV at  $1 \times 10^{15} \text{e/cm}^2$  is shown which is a criterion for evaluating the radiation resistance. In contrast to the parenthesized remaining factor of 69.5 % of the maximum power  $P_{\text{max}}$  after electron irradiation with the initial output characteristic as 100 % in the conventional solar cell (a) corresponding to

Fig. 8, the remaining factor of maximum power  $P_{\max}$  after electron irradiation is 67.0 % in the solar cell (b) corresponding to Fig. 10. Although not shown in table 1, the solar cell corresponding to Fig. 9 has a similar remaining factor of maximum power  $P_{\max}$  after electron irradiation.

#### SUMMARY OF THE INVENTION

In view of the foregoing, an object of the present invention is to provide a Si space solar cell of high output sufficiently improved in radiation resistance.

According to an aspect of the present invention, a silicon solar cell includes a p type silicon substrate, an n type diffusion layer formed at a first main surface side in the substrate, and a  $p^+$  layer of high doping concentration formed by ion implantation of aluminum (Al) at a second main surface side in the substrate. In this silicon solar cell, Al in the  $p^+$  layer formed by ion implantation easily combines with oxygen. Therefore, oxygen in the p type silicon substrate is applied to gettering effectively by the  $p^+$  layer to improve radiation resistance.

According to another aspect of the present invention, a silicon solar cell includes a p type silicon substrate, an n type diffusion layer formed at a first main surface side in the substrate, a  $p^+$  layer of high doping concentration formed at least partially at a second main surface side in the substrate by ion implantation of the group III element having an atomic radius greater than that of a Si atom, an oxide film on the second main surface of the substrate with an opening, and an electrode electrically connected to the  $p^+$  layer via the opening of the oxide film. A conventional silicon solar cell including an oxide film is disadvantageous in that recombination of carriers increases due to the interface of Si and the oxide film being damaged by hot carriers generated within the n type diffusion layer by ultraviolet ray irradiation arriving at the interface. In the silicon solar cell of the present aspect, damage towards the interface between the p type substrate region and the  $p^+$  region formed by ion implantation is suppressed since hot carriers have their energy reduced significantly in passing through the interface due to an abrupt change in the doping concentration and formation of atomic level distortion in the vicinity of the interface. As a result, recombination of carriers is prevented to avoid reduction in the output of a solar cell by ultraviolet ray irradiation.

According to a further aspect of the present invention, a silicon solar cell has a  $p^+$  layer formed by ion implantation of Al all over the entire region of the back surface of a p type silicon substrate. Oxygen gettering by Al is effected all over the back surface of the substrate, whereby radiation resistance of a solar cell is improved over the entire region of the back surface of the substrate.

According to yet another aspect of the present invention, a method of fabricating a silicon solar includes the steps of forming an n type diffusion layer at a first main surface side within a p type silicon substrate,

forming an oxide film so as to cover a second main surface of the p type substrate, forming a  $p^+$  layer of high doping concentration at the second main surface side within the p type substrate by ion implantation of the group III element having an atomic radius greater than that of a Si atom via the oxide film, forming an opening in the oxide film, and forming an electrode electrically connected to the  $p^+$  layer via the opening. According to the method of fabricating a silicon solar cell, ions for forming the  $p^+$  layer are implanted into the p type substrate through the oxide film after its formation. Therefore, the interface between the p type substrate and the oxide film can be maintained at its relatively favorable situation prior to ion implantation.

The foregoing and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when taken in conjunction with the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a sectional view schematically showing a silicon solar cell according to an embodiment of the present invention.

Fig. 2 is a sectional view of a solar cell according to another embodiment of the present invention.

Fig. 3 is a sectional view of a solar cell according to a further embodiment of the present invention.

Figs. 4A-4D are sectional views of the solar cell of Fig. 2 for describing the fabrication method thereof.

Figs. 5A-5D are sectional views of the solar cell of Fig. 2 showing fabrication steps following the step of Fig. 4D.

Fig. 6 shows the energy band structure along the cross section where a back surface oxide film is located in a solar cell of Fig. 9.

Fig. 7 shows the energy band structure along the cross section of the solar cell of Fig. 1.

Fig. 8 is a sectional view of a conventional solar cell.

Fig. 9 is a sectional view of another conventional solar cell.

Fig. 10 is a sectional view of a further conventional solar cell.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

The most important feature of the present invention is to obtain the following two effects (B1) and (B2) by ion-implantation of the group III element such as Al onto the back surface side of a silicon substrate in a Si space solar cell of high efficiency.

(B1) Allow gettering of oxygen from the Si substrate by the group III element such as Al to improve radiation resistance of a silicon solar cell.

(B2) Altering the doping concentration abruptly by ion implantation and form atomic level distortion in the vicinity of the interface between a p<sup>+</sup> region provided for collecting carriers efficiently and a p type substrate. Since the atomic level distortion acts to reduce significantly the energy of hot carriers, reduction in the output of a silicon solar cell due to ultraviolet ray irradiation can be avoided.

According to the present invention, a Si space solar cell can be provided superior in ultraviolet ray resistance and radiation resistance.

Fig. 1 schematically shows a BSFR type Si space solar cell according to an embodiment of the present invention. In the solar cell of Fig. 1, an n type diffusion layer 2 is formed at a front light receiving surface side of a p type Si substrate 1. A p<sup>+</sup> type layer (BSF layer) 3a is formed at the back surface of substrate 1. A back surface oxide film 6 is formed on p<sup>+</sup> type layer 3a. A front surface oxide film 7 is provided on n type diffusion layer 2. A front electrode 4 and a back electrode 5 are formed at the front surface side and the back surface side, respectively, of the substrate. The doping concentration is altered abruptly in the vicinity of an interface 8 between p<sup>+</sup> type layer 3a and p type Si substrate 1. Distortion in atomic level is formed in the vicinity of interface 8 between p<sup>+</sup> type layer 3a and p type Si substrate 1 and within p<sup>+</sup> type layer 3a. As will be described in detail afterwards, an abrupt change in doping concentration and atomic level distortion in the vicinity of interface 8 between p<sup>+</sup> type layer 3a and p type Si substrate 1 can be implemented by implanting ions having an atomic radius greater than that of Si (for example, Al) into p type Si substrate 1 to form a p<sup>+</sup> type layer 3a. The atomic radius of Si is 1.17 Å, whereas the atomic radius of Al is 1.41 Å.

The reason why radiation resistance in the solar cell of Fig. 1 is improved significantly will be described hereinafter.

Reduction in the output of a solar cell by irradiation of radioactive rays and the like is considered to be caused by two main factors. One is the direct influence towards the solar cell by electrons which are particles of high energy. The other is the indirect influence towards the solar cell by ultraviolet rays and the like which are photons.

As to the direct effect towards a solar cell, irradiation of a solar cell with electron rays causes the formation of a vacancy in the semiconductor crystal of the cell base material, a complex where a vacancy and an interstitial impurity atom are combined, and a cluster of defects thereof, as previously mentioned in the section of the background art. The output of the solar cell cannot be derived effectively since these lattice defects act as a recombination center.

As to the indirect effect by ultraviolet ray, it is known that hot carriers generated in a silicon substrate apply damage to the binding at the Si/SiO<sub>2</sub> interface when ultraviolet ray having relatively high energy is applied to

a solar cell, as described by P.E. Gruenbaum et al. in Applied Physics Letters 52 (17), 25, April 1988. Since the damaged portion at the Si/SiO<sub>2</sub> interface becomes the recombination center, the passivation effect of the SiO<sub>2</sub> film is degraded to lower the output of the solar cell.

Fig. 6 is an energy band structure for describing the indirect effect by ultraviolet ray. The energy band structure of Fig. 6 shows the band structure and the flow of hot carriers at a cross sectional face where semiconductor substrate 1 is directly in contact with back surface oxide film 6 in the solar cell of Fig. 10. E<sub>C</sub> indicates the lower limit of the conduction band, E<sub>V</sub> indicates the upper limit of the valence band, and E<sub>F</sub> indicates the Fermi level. The "—" sign at the interface between semiconductor substrate 1 and back surface oxide film 6 indicates the interface level. In general, a depletion region is formed at the Si/SiO<sub>2</sub> interface. When a solar cell having the band structure as shown in Fig. 6 is irradiated with ultraviolet rays (UV), hot carriers (electron e and hole h) are generated mainly at the vicinity of the front surface. These hot carriers pass through Si substrate 1 maintaining its high energy to arrive at the Si/SiO<sub>2</sub> interface to apply damage to the binding at the interface. The damage at the interface acts as the recombination center of carriers. This means that the probability of electrons of the minority carriers generated by absorbing solar light recombining with holes of the majority carriers via the recombination center of the Si/SiO<sub>2</sub> interface increases. As a result, it will become difficult to effectively provide the minority carriers generated by photoelectric conversion outside the solar cell as the output. In other words, the effect of back surface passivation is degraded by the hot carriers.

The inventor noted the direct effect by high energy particles to the cell and the indirect effect by photons, and carried out extensive research to implement a solar cell without any output degradation by energy particles of electron rays and that can prevent formation of a recombination center of carriers at a Si/SiO<sub>2</sub> interface by reducing the energy of hot carriers generated by photons of ultraviolet ray before they reach the interface. The inventor finally conceived of a silicon solar cell having the structure of Fig. 1. More specifically, by implanting to the back surface side of substrate 1 ions of the group III element such as Al having an atomic radius greater than that of a Si atom, the above-described problems of the direct and indirect effects towards the cell can be solved to obtain the two advantages set forth in the following.

The first advantage is that the radiation resistance of a solar cell can be improved by the provision of a p<sup>+</sup> layer 3a formed by ion-implantation of the group III element such as Al. Oxygen from Si substrate 1 is subjected to gettering by p<sup>+</sup> layer 3a. As a ground thereof, there is a description in, for example, "Semiconductors and Semimetals", volume 11, Solar Cells: Academic Press, pp. 154-157 that the oxygen in a Si substrate is responsible for radiation-induced defect, and a solar cell

exhibits superior radiation resistance if the containing amount of oxygen is low. The inventor considered that the radiation resistance of a solar cell can be improved by doping Al at high concentration into Si substrate 1 to take advantage of the fact that Al recombines easily with oxygen to effectively getter the oxygen in Si substrate 1. A solar cell of a structure similar to that shown in Fig. 8 provided that p<sup>+</sup> layer 3 is formed of an Al-Si alloy layer was actually fabricated and subjected to experiments. As shown in solar cell (c) in Table 1, a remaining factor of 73.3 % was obtained with respect to maximum power P<sub>max</sub> after electron irradiation of 1 MeV at 1 × 10<sup>15</sup> e/cm<sup>2</sup> which is the criterion of evaluating the radiation resistance. It is appreciated from this value that the radiation resistance is improved in contrast to the values of 67.70 % - 69.5 % of the retaining rate of the maximum power P<sub>max</sub> in conventional solar cells.

In solar cell (a), p<sup>+</sup> layer 3 was formed by diffusing boron into p type Si substrate 1 in a gas atmosphere including boron in a furnace of a high temperature (approximately 1000°C). In solar cell (c), p<sup>+</sup> layer 3 of a Si-Al alloy layer was formed by applying paste including Al powder on Si substrate 1 and baking the same in a furnace of approximately 400°C for a short time period. There is a problem that the solar absorptance α<sub>s</sub> in solar cell (c) is increased to result in a higher cell temperature in contrast to those of solar cells (a) and (b). Therefore, maximum power P<sub>max</sub> · T<sub>OP</sub> of solar cell (c) in an operating temperature is 75.1 mW, which is lower than those of cells (a) and (b). According to the embodiment of the present invention, the solar cell of Fig. 1 has Al atoms implanted. Therefore, a thick p<sup>+</sup> layer 3 of Si-Al alloy such as in cell (c) in Table 1 will not be formed. Therefore, the problem of increase in temperature of the cell does not occur.

Another advantage by ion-implantation is that a structure can be achieved in which the doping concentration changes abruptly from p type substrate 1 to p<sup>+</sup> layer 3 at the vicinity of the interface 8 between p<sup>+</sup> layer 3a and p type substrate 1 provided for efficiently collecting carriers and in which distortion of the atomic level is formed. As a result, hot carriers generated within n type diffusion layer 2 due to ultraviolet irradiation lose their energy in passing through the vicinity of interface 8 from p type substrate 1 to p<sup>+</sup> layer 3a. In other words, interface 9 between p<sup>+</sup> layer 3a and oxide film 6 will be protected from hot carriers. Thus, the problem of recombination of carriers at the damaged portion in interface 9 is eliminated to avoid reduction in output caused by ultraviolet irradiation.

Fig. 7 shows the energy band structure and the flow of hot carriers in the solar cell of Fig. 1 for the purpose of describing the effect of ion-implantation. The energy band structures of Figs. 7 and 6 are similar, provided that the band structure of p<sup>+</sup> layer 3a formed by ion implantation is included in the energy band structure of Fig. 7. In Fig. 7, interface 8 between n type Si substrate 1 and p<sup>+</sup> layer 3a is indicated with a "+" sign.

Description was made with reference to Figs. 6 and 7 as though hot carriers (electron e, hole h) per se generated by ultraviolet rays (UV) apply damage at the interface between Si and an oxide film in order to facilitate the description of the behavior of hot carriers and the effect of the present invention. In practice, a plurality of electrons e and holes h are present within the Si substrate during operation of a solar cell. It is to be noted that the generated hot carrier per se may not always apply damage, and that another carrier of the same type receiving energy from the hot carrier applies damage.

The solar cell of Fig. 1 is only a way of example of the present invention. The present invention can be applied to other various types of solar cells. For example, a texture structure can be introduced into the light receiving surface of the solar cell of Fig. 1, as shown in Fig. 2. A method of fabricating the solar cell of Fig. 2 according to the present invention will be described hereinafter with reference to Figs. 4A-4D and Figs. 5A-5D.

Referring to Fig. 4A, a p type silicon substrate 1 (having a carrier concentration of 1 × 10<sup>15</sup>/cm<sup>3</sup> - 1 × 10<sup>16</sup>/cm<sup>3</sup>, and a resistance of 1 - 3 Ωcm) is etched to a predetermined thickness (approximately 50 - 200 μm).

Referring to Fig. 4B, a non-reflective surface configuration 10 is formed at the front surface of substrate 1. Configuration 10 can be realized by processing a SiO<sub>2</sub> film deposited by CVD on the surface of substrate 1 by the well-known photolithography and etching the same with an alkali type etchant.

Referring to 4C, an n layer 2 is formed by thermal diffusion of impurities of the group V (phosphorus and the like) from the front surface of substrate 1. In this case, the back surface of substrate 1 is protected by a thick oxide film 6 formed by thermal oxidation in, for example, dry oxygen.

Referring to Fig. 4D, impurities of the group III (Al here) having an atomic radius greater than that of Si are ion-implanted at the back surface side of substrate 1 through oxide film 6. This ion-implantation is the most important feature of the present invention. The thickness of p<sup>+</sup> layer 3a is set to approximately 1 - several μm, and the carrier concentration thereof is set to at least 1 × 10<sup>18</sup>/cm<sup>3</sup>. By implanting impurities of the group III having an atomic radius greater than that of Si into the back surface of substrate 1, and the doping concentration is altered abruptly and distortion in atomic level is formed in the vicinity of interface 8 between p<sup>+</sup> layer 3a and p type substrate 1. Even if hot carriers are generated within n type diffusion layer 2 and the like by ultraviolet irradiation, the hot carriers will lose energy in passing through the vicinity of interface 8. Therefore, the bonds at interface 9 between oxide film 6 and p<sup>+</sup> layer 3a will not be damaged by the hot carriers. Thus, degradation in the output of a solar cell can be avoided.

Since ion implantation of Al atoms into p type substrate 1 is carried out through oxide film 6 after formation thereof, interface 9 between p type substrate 1 and oxide film 6 can be maintained at a relatively favorable

situation prior to ion implantation. It is possible to carry out ion implantation prior to formation of oxide film 6. In this case, oxide film 6 will be formed on p<sup>+</sup> layer 3a having high impurity concentration. In general, formation of oxide film 6 of small interface states and favorable interface characteristics can be expected as the impurity concentration of the substrate is lower. Formation of an ideal oxide film 6 is difficult when the oxide film is to be formed on p<sup>+</sup> layer 3a having high concentration. Therefore, it is preferable to implant ions of Al after oxide film 6 is formed on p type substrate 1 as shown in Fig. 4D.

The above-described ion implantation does not require a high carrier concentration (for example,  $5 \times 10^{19} - 1 \times 10^{20}/\text{cm}^3$ ) in p<sup>+</sup> layer 3 as in the case where conventional thermal diffusion is carried out. This is because a back surface passivation effect of a sufficient level can be expected since Si/SiO<sub>2</sub> interface 9 is formed that has less interface states that function as the recombination levels of carriers. Thus, the carrier concentration does not have to be increased to a level as high as in the conventional case. Damage by ion irradiation can occur at the back surface of the cell even by the ion implantation shown in Fig. 4D. Recovery of this damage is carried out at the next step.

Referring to Fig. 5A, recovery of damage caused by ion-implantation is effected by RTA (Rapid Thermal Anneal) at 600°C, for example, for a few minutes. Such a thermal treatment of this level will not effect the pn junction p type substrate 1 and n type substrate 2 or at interface 8 between substrate 1 and p<sup>+</sup> layer 3a. By introducing dry oxygen of a predetermined concentration into the furnace simultaneous to this RTA method, front surface oxide film 7 can be formed at the same step. The thickness of front surface oxide film 7 is set to 100-200 Å, for example.

Referring to Fig. 5B, openings 11 and 12 are formed at predetermined positions in front surface oxide film 7 and back surface oxide film 6 by the well-known photolithograph method. The etching process can be carried out by any of wet etching and dry etching.

Referring to Fig. 5C, a front electrode 4 is formed by the well known photolithography method.

Referring to Fig. 5D, back electrode 5 is formed so as to cover back surface oxide film 6 and opening 12.

Then, thermal treatment is applied after forming an anti-reflective coating at the front surface side of substrate 1 (not shown). The cell is cut out to a predetermined dimension to be completed as a bare cell. A solar cell with cover glass is obtained by adhering cover glass on the light receiving surface of the bare cell via resin.

Although ion of Al atoms are implanted in the above described embodiment, other ions of the group III element such as Ga (having an atomic radius of 1.25 Å greater than the atomic radius of 1.17 Å of Si) can be used.

Fig. 3 shows a solar cell according to a further embodiment of the present invention. The appearance of the solar cell of Fig. 3 is similar to the conventional solar cell of Fig. 8. The solar cell of Fig. 3 does not

include oxide films 6 and 7 as in the solar cell of Fig. 1. The aforementioned problem (B2) of damage at the Si/SiO<sub>2</sub> interface by hot carriers does not occur in the solar cell of Fig. 3. However, the problem of (B1) of output degradation by radioactive ray irradiation is present. Therefore, the radiation resistance can be improved in the solar cell of Fig. 3 by implanting ions such as Al having a great recombination ability with oxygen in forming p<sup>+</sup> layer 3a. Although Al is used as the atoms to be driven by ion-implantation in the embodiment of Fig. 3, an element of group III that has an atomic radius greater than that of Si atoms and has a relatively high combination with oxygen such as Ga can be used.

(d) in Table 1 represents the characteristics of the solar cell of Fig. 1 which is a recent protocol by the inventor. It is appreciated from Table 1 that initial maximum power  $P_{\text{max}}$  of solar cell (d) is equal to that of a conventional cell (b) of high efficiency, and the remaining factor after electron irradiation is superior than that of solar cell (c) using Al paste. Furthermore, since solar cell (d) does not have a thick Si-Al alloy layer 3 formed as in solar cell (c), the solar absorptance  $\alpha_s$  can be lowered than that of cell (c), and maximum output  $P_{\text{max}} \cdot T_{\text{OP}}$  under the operating temperature after electron irradiation can be improved. As to the effect of ultraviolet irradiation, no degradation in the output characteristics was observed at an elapse of 700 sun · hours (1 sun represents the intensity of normal solar light) in solar cell (d). Thus, the superior advantage of the present invention was confirmed.

According to one aspect of the present invention, p<sup>+</sup> layer at the back surface side of a p type silicon substrate is formed by ion-implantation. Since Al easily combines with oxygen, the oxygen within the p type substrate is effectively gettered by the p<sup>+</sup> layer, whereby the radiation resistance of the silicon solar cell is improved.

According to another aspect of the present invention, the doping concentration is altered abruptly, and distortion in atomic level is formed in the vicinity of the interface between a p<sup>+</sup> layer formed by implanting ions of group III element having an atomic radius greater than that of Si atom and a p type substrate. Therefore, hot carriers generated within the n type diffusion layer by ultraviolet ray irradiation loses its energy in passing through this interface between the p<sup>+</sup> layer and the p type substrate, so that the interface between the p<sup>+</sup> layer and the oxide film is protected from hot carriers. As a result, recombination of carriers generated by the damage portion caused by hot carriers at the interface between a p<sup>+</sup> region and an oxide film encountered in prior art is prevented, and output degradation caused by ultraviolet irradiation is avoided in a silicon solar cell.

According to a further aspect of the present invention, a p<sup>+</sup> layer is formed all over the back surface of a p type silicon substrate. Gettering of oxygen by Al is carried out all over the entire region of the back surface of the substrate. Therefore, radiation resistance of a silicon solar cell is improved sufficiently. Since the entire

region of the back surface of the substrate is protected from hot carriers, output degradation by ultraviolet irradiation in a solar cell can be sufficiently avoided.

According to yet another aspect of the present invention, an oxide film is formed at the back surface of a p<sup>+</sup> type silicon substrate and then a p<sup>+</sup> layer is formed by implanting ions through the oxide film. Therefore, the interface between the substrate and the oxide film can be maintained at a relatively favorable situation prior to ion implantation.

Although the present invention has been described and illustrated in detail, it is clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of the present invention being limited only by the terms of the appended claims.

#### Claims

1. A silicon solar cell comprising:
  - a p type silicon substrate (1),
  - an n type diffusion layer (2) formed at a first main surface side in said p type substrate (1), and
  - a p<sup>+</sup> layer (3a) of high doping concentration formed by ion-implantation of group III element having an atomic radius greater than that of Si at a second main surface side in said p type substrate (1).
2. The silicon solar cell according to claim 1, wherein said p<sup>+</sup> layer (3a) of high doping concentration is formed all over said second main surface.
3. The silicon solar cell according to claim 1, wherein said group III element is Al.
4. A silicon solar cell comprising:
  - a p type silicon substrate (1),
  - an n type diffusion layer (2) formed at a first main surface side in said p type substrate (1),
  - a p<sup>+</sup> layer (3a) of high doping concentration formed at least partially at a second main surface side in said p type substrate (1) by ion-implantation of group III element having an atomic radius greater than that of Si atom,
  - an oxide film (6) formed on said second main surface and including an opening, and
  - an electrode (5) formed on said oxide film (6) and electrically connected to said p<sup>+</sup> layer (3a) via said opening.
5. The silicon solar cell according to claim 4, wherein said p<sup>+</sup> layer (3a) of high doping concentration is formed all over said second main surface.
6. The silicon solar cell according to claim 4, wherein said group III element is Al.
7. A method of fabricating a silicon solar cell comprising the steps of:
  - forming an n type diffusion layer (2) at a first main surface side in a p type silicon substrate (1),
  - forming an oxide film (6) so as to cover a second main surface of said p type substrate (1),
  - forming a p<sup>+</sup> layer (3a) of high doping concentration at least partially at said second main surface side within said p type substrate (1) by ion-implanting group III element having an atomic radius greater than that of a Si atom via said oxide film (6),
  - forming an opening in said oxide film (6), and
  - forming an electrode (5) electrically connected to said p<sup>+</sup> layer (3a) via said opening.
8. The method of fabricating a silicon solar cell according to claim 7, wherein said group III element is Al.



FIG. 1

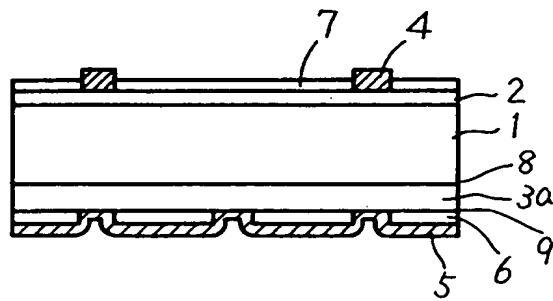


FIG. 2

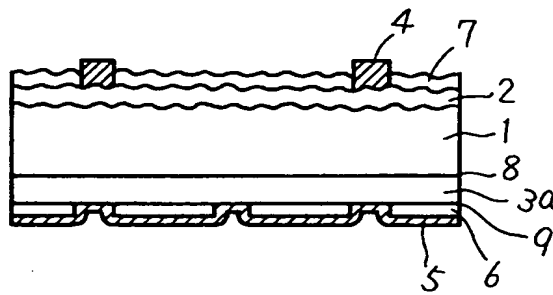


FIG. 3

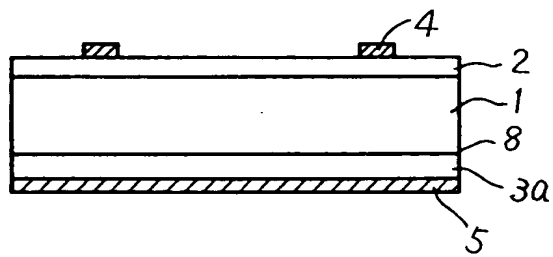


FIG. 4A



FIG. 4B

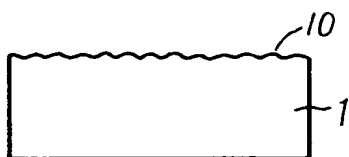


FIG. 4C

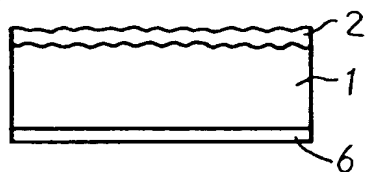


FIG. 4D

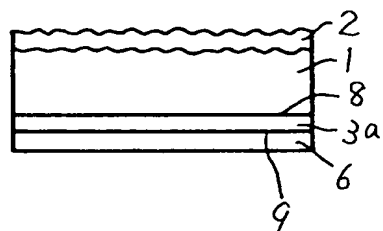


FIG. 5A

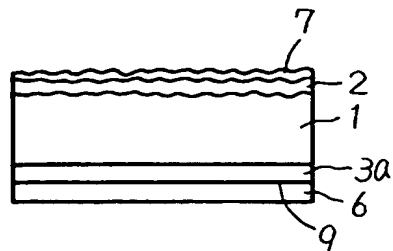


FIG. 5B

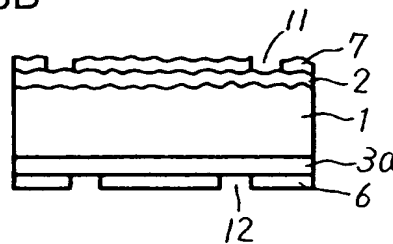


FIG. 5C

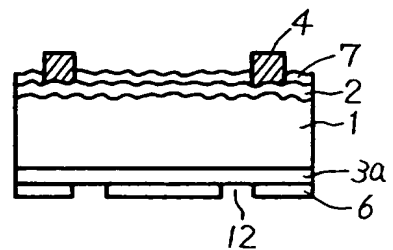


FIG. 5D

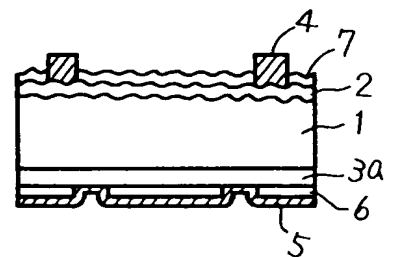


FIG. 6

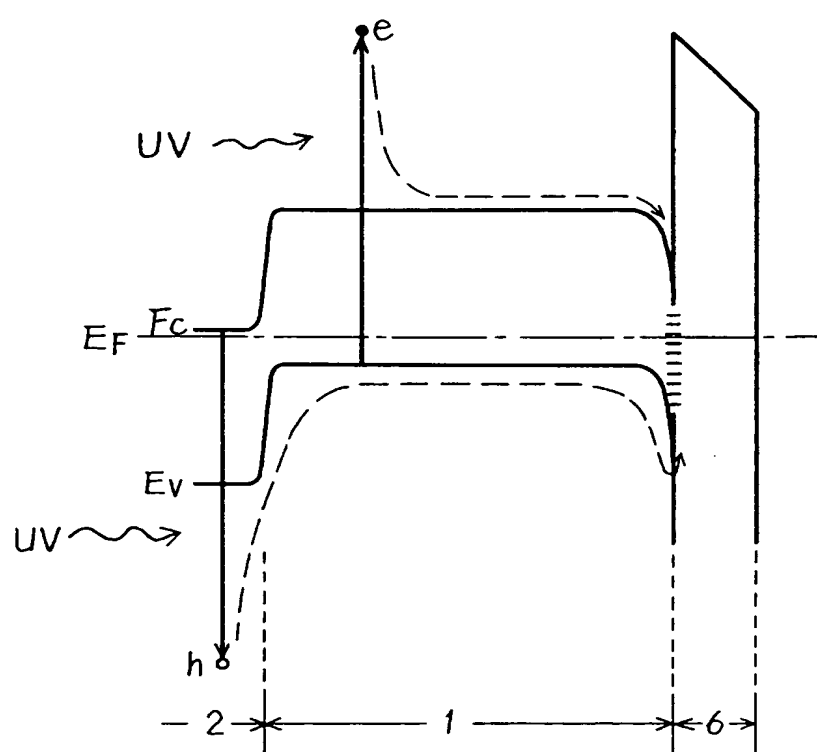


FIG. 7

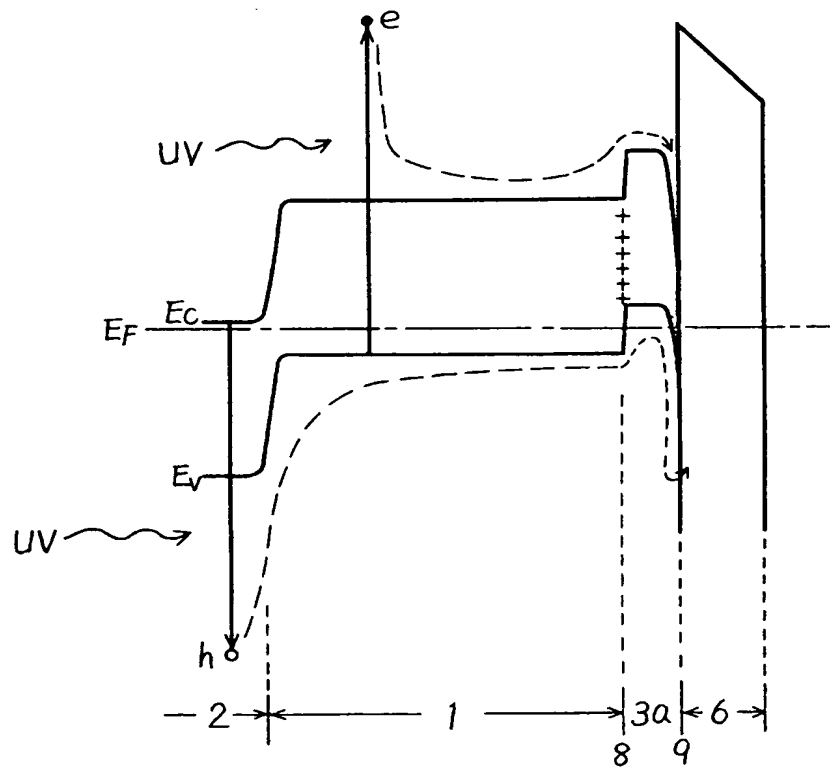


FIG. 8

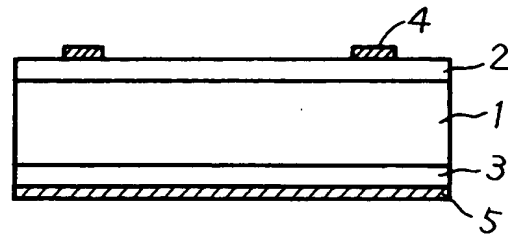


FIG. 9

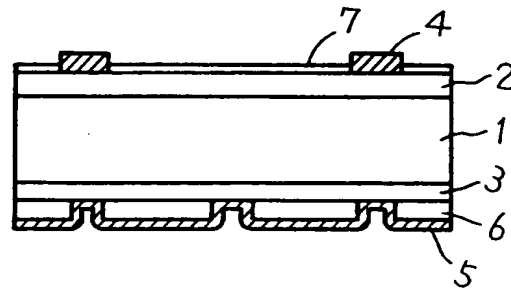


FIG. 10

